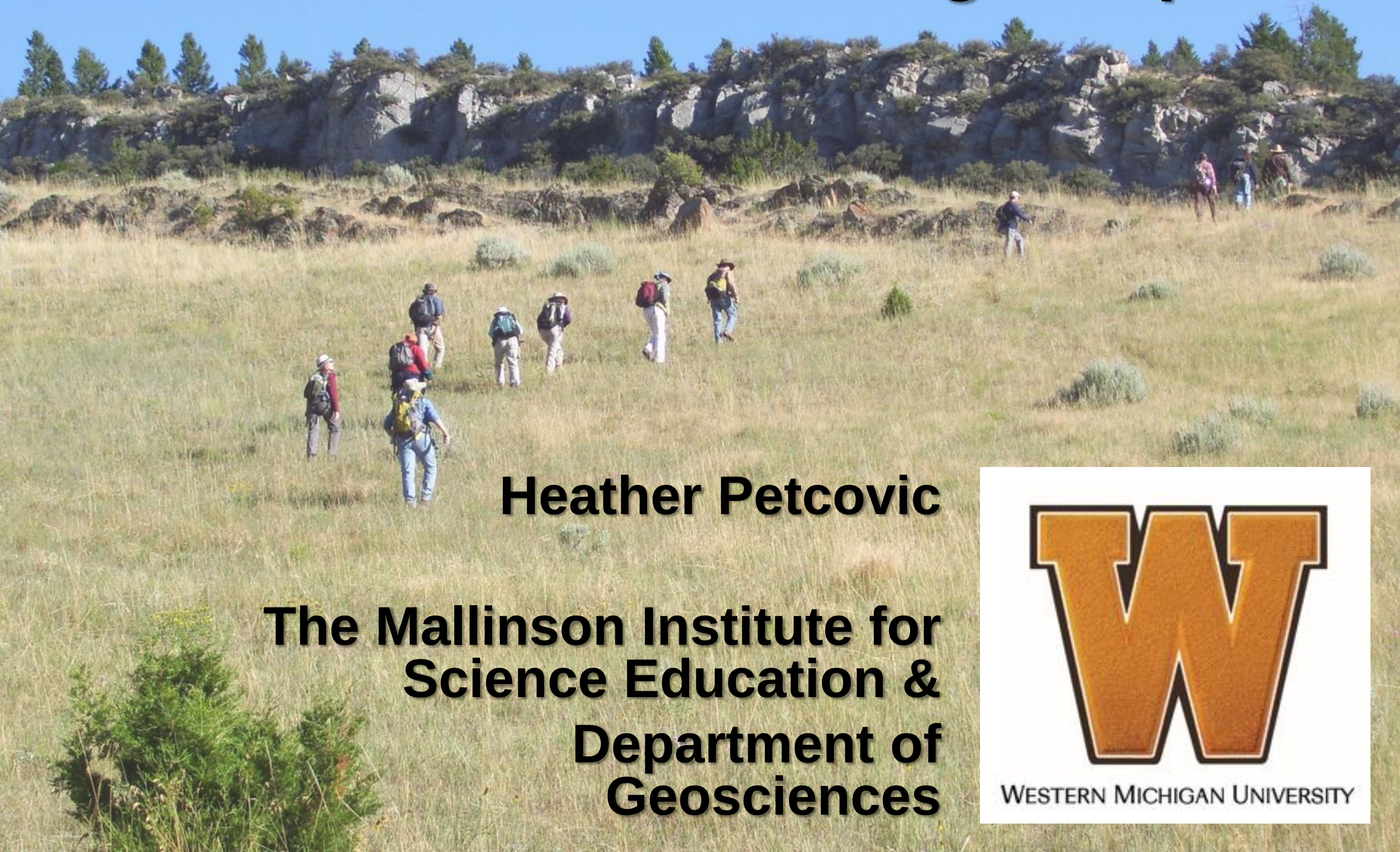
Thinking in the Field: How Experts and Novices Make a Geologic Map



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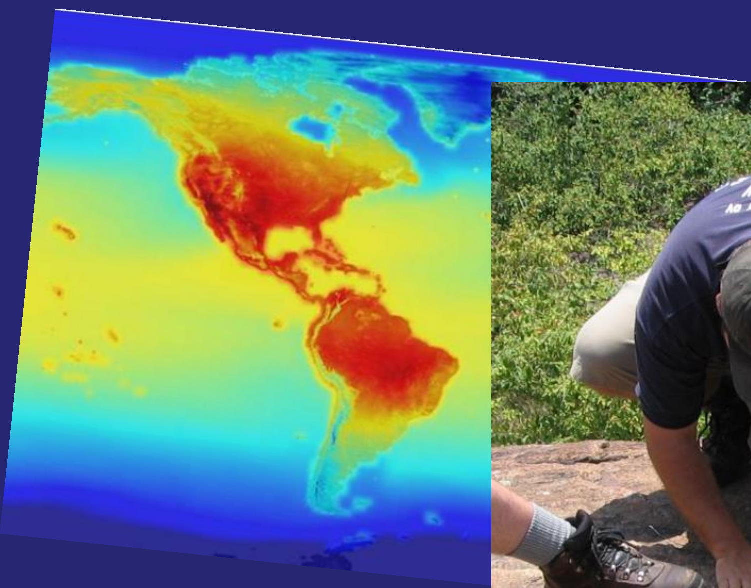
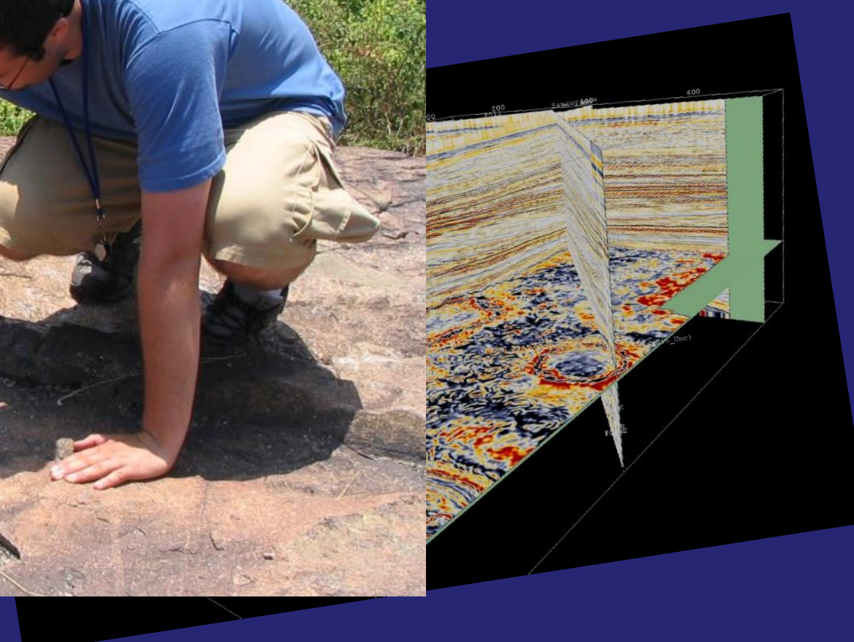
Where Are We Heading?

1. Why study expert and novice geologists in the field?
2. The research study: How novices and experts make a geologic map
   - Study 1: Spatial thinking & geologic knowledge
   - Study 2: Movement
   - Study 3: Movement choices
3. Implications for instruction

Why Study Fieldwork?

"The reading of books and the study of specimens will never make the geologist; the geologist is made in the field, not in the laboratory" (Himus and Sweeting, 1955).





Petcovic et al., 2014

Why Study Geologic Mapping?

Mapping is a cognitively demanding task done in the “wild.”

Why Study Experts and Novices?

RTS:

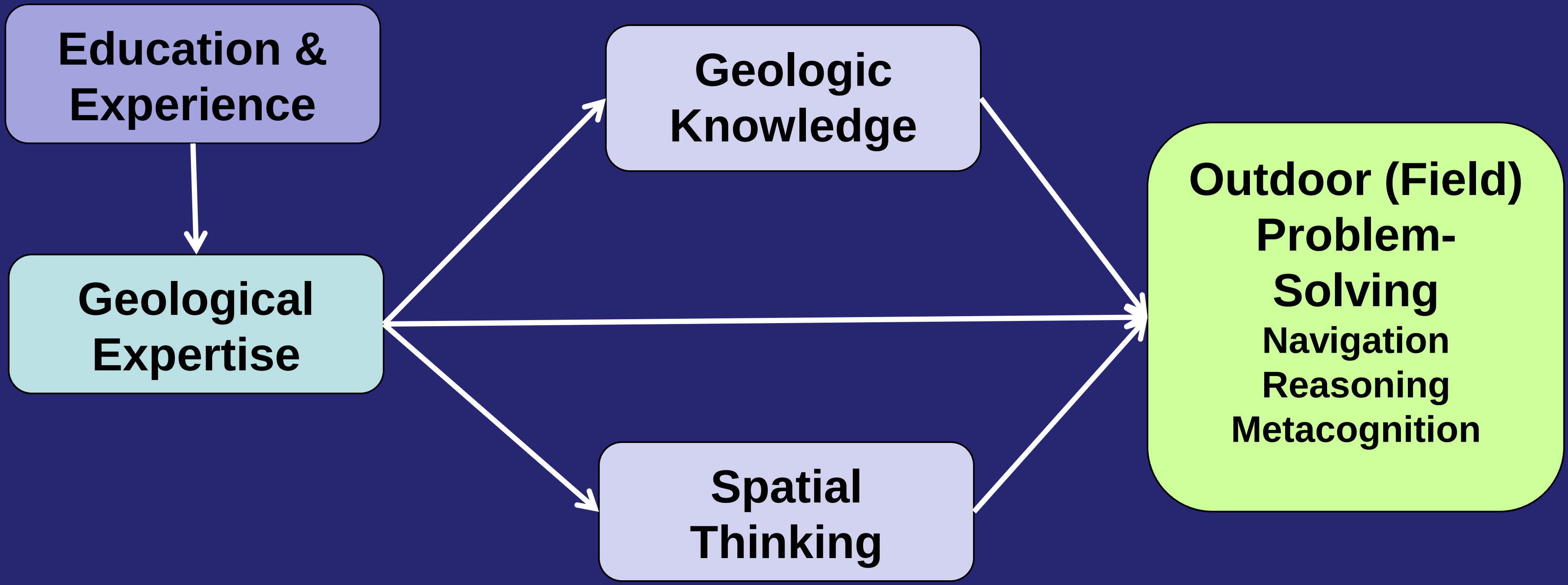
- ve deeper, more terconnected knowledge
- Perceive and recognize patterns
- Have flexible thought processes
- Are aware of complexities
- Can self-monitor

Synthesized from Chase & Simon, 1973; Chi et al., 1981; Feltovich et al., 1997; Wineberg, 1998; Bransford et al., 2000; Hmelo-Silver and Nagarajan, 2002; Hoz et al., 2001; Donovan and Bransford, 2005; Ericsson, 2006

The Research Study

PURPOSE

Examine how cognitive processes that underlie thinking and skills in geologic mapping change from novice to expert.



Five-year project in which N=67 novice (undergraduate) through expert (professional) geologists completed a suite of lab and field tasks.

The Research Study

PARTICIPANTS

- Cohorts of 9-10 participants (2009=29; 2010=38)
  - 54% male, mean 36.5 yrs (range 20-68), ~95% white

Experience	% of Total Sample
Current undergrad student	21
Current graduate student	28
Current/former professional	55
Has Masters/PhD	40/24
Undergr structural geology	82
Undergr field course/mapping	96/75
Graduate fieldwork/mapping	66/33
Professional mapping/teaching	32

The Research Study

STUDY 1: How do geologic knowledge and spatial thinking skill impact novice and expert participants' ability to map the distribution of rock types in a field area?

Construct	Task or Measure
Expertise	Domain Experience Questionnaire (General and Mapping)
Geologic Knowledge	Geoscience Concept Inventory (GCI+) (Libarkin & Anderson, 2005)
Spatial Thinking	VSR - Paper Folding, Form Board, Space Relations (Ekstrom et al., 1976; Bennett et al., 1972)
	WMC - Matrix Span, Arrow Span (Hambrick & Oswald, 2005)
	PS - Pattern Comparison (Salthouse & Babcock, 1991)
Field Problem-Solving: Geologic Mapping Task	Bedrock geologic map (scanned and digitized)
	GPS track during mapping (ArcGIS)
	Post-mapping Interview

Hambrick et al., 2012

The Research Study

STUDY 2: How do patterns of movement compare between experts and novices as they map the field area?

Construct	**Task or Measure**
Expertise	Domain Experience Questionnaire (General and Mapping)
Geologic Knowledge	Geoscience Concept Inventory (GCI+) (Libarkin & Anderson, 2005)
Spatial Thinking	VSR - Paper Folding, Form Board, Space Relations (Ekstrom et al., 1976; Bennett et al., 1972)
	WMC - Matrix Span, Arrow Span (Hambrick & Oswald, 2005)
	PS - Pattern Comparison (Salthouse & Babcock, 1991)
Field Problem-Solving: Geologic Mapping Task	Bedrock geologic map (scanned and digitized)
	GPS track during mapping (ArcGIS)
	Post-mapping Interview

Baker et al., 2012; Baker et al., 2016; Baker & Petcovic, 2016

The Research Study

STUDY 3: What do novices and experts say about their maps and their choices for how to move through the study area?

Construct	Task or Measure
Expertise	Domain Experience Questionnaire (General and Mapping)
Geologic Knowledge	Geoscience Concept Inventory (GCI+) (Libarkin & Anderson, 2005)
Spatial Thinking	VSR - Paper Folding, Form Board, Space Relations (Ekstrom et al., 1976; Bennett et al., 1972)
	WMC - Matrix Span, Arrow Span (Hambrick & Oswald, 2005)
	PS - Pattern Comparison (Salthouse & Babcock, 1991)
Field Problem-Solving: Geologic Mapping Task	Bedrock geologic map (scanned and digitized)
	GPS track during mapping (ArcGIS)
	Post-mapping Interview

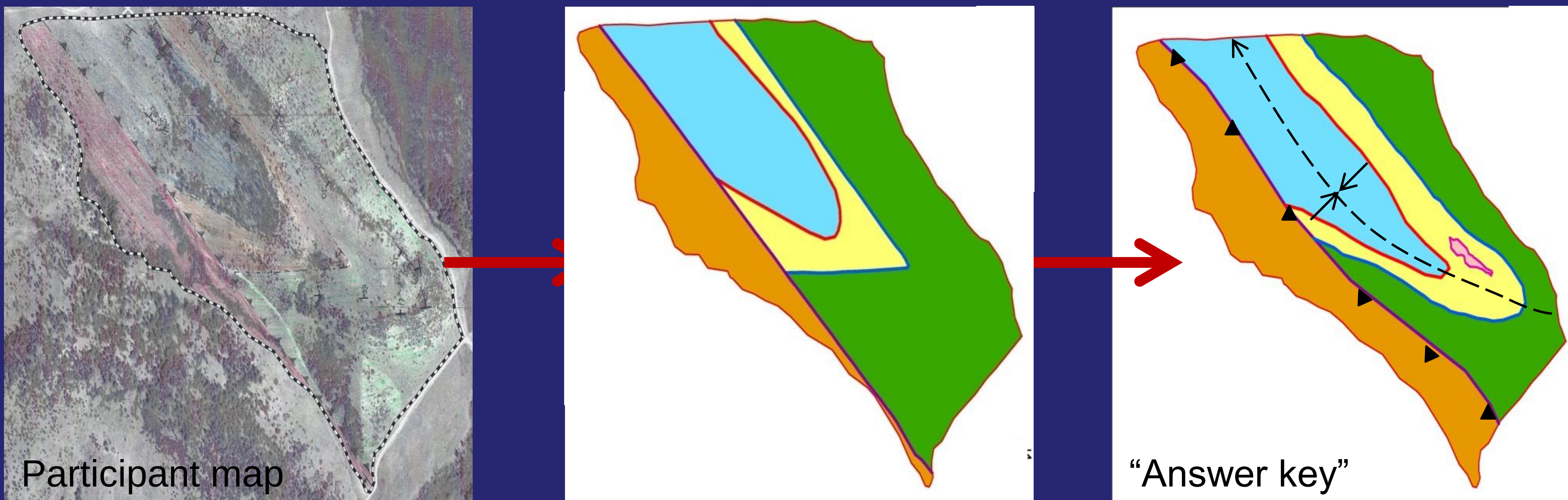
Petcovic et al., in prep

The Bedrock Mapping Task

METHODS

- Group guided introduction to rock types (4 major types)
- Individual mapping
- Unlimited time (5-7 hrs)
- Aerial photo and topo map
- Rocky Mountains (MT)

“Success” = Map Score



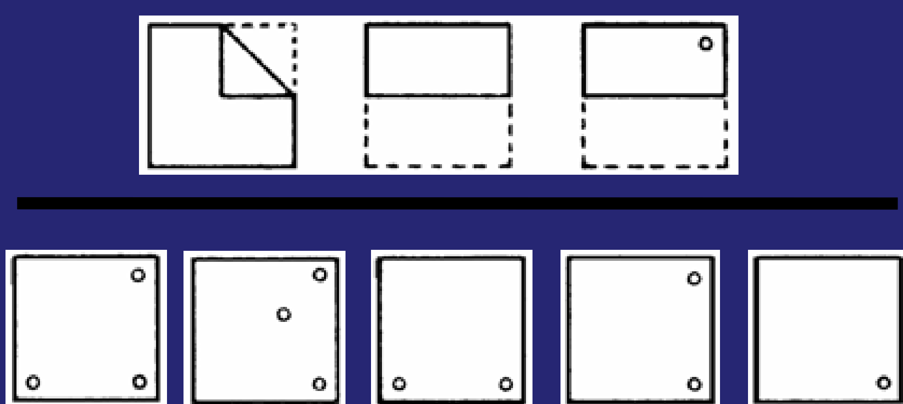
PARTICIPANT MAP ANALYSIS – TWO SCORES

- **SURFACE ROCK DISTRIBUTION** = ArcGIS accuracy of % of 1 m digitized participant pixels matching “key”
- **GEOLOGIC STRUCTURE** = presence and accuracy of major fold and fault in map area (rubric score out of 8 points)

Study 1: Methods

SPATIAL THINKING

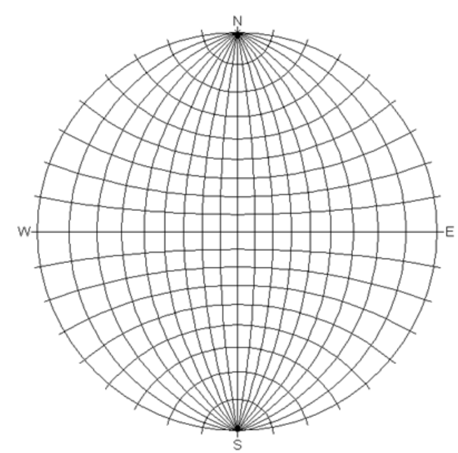
- Pencil/paper and computer-based tests
- Some timed, group administration
- Some self-paced, individual
- Create a spatial composite score



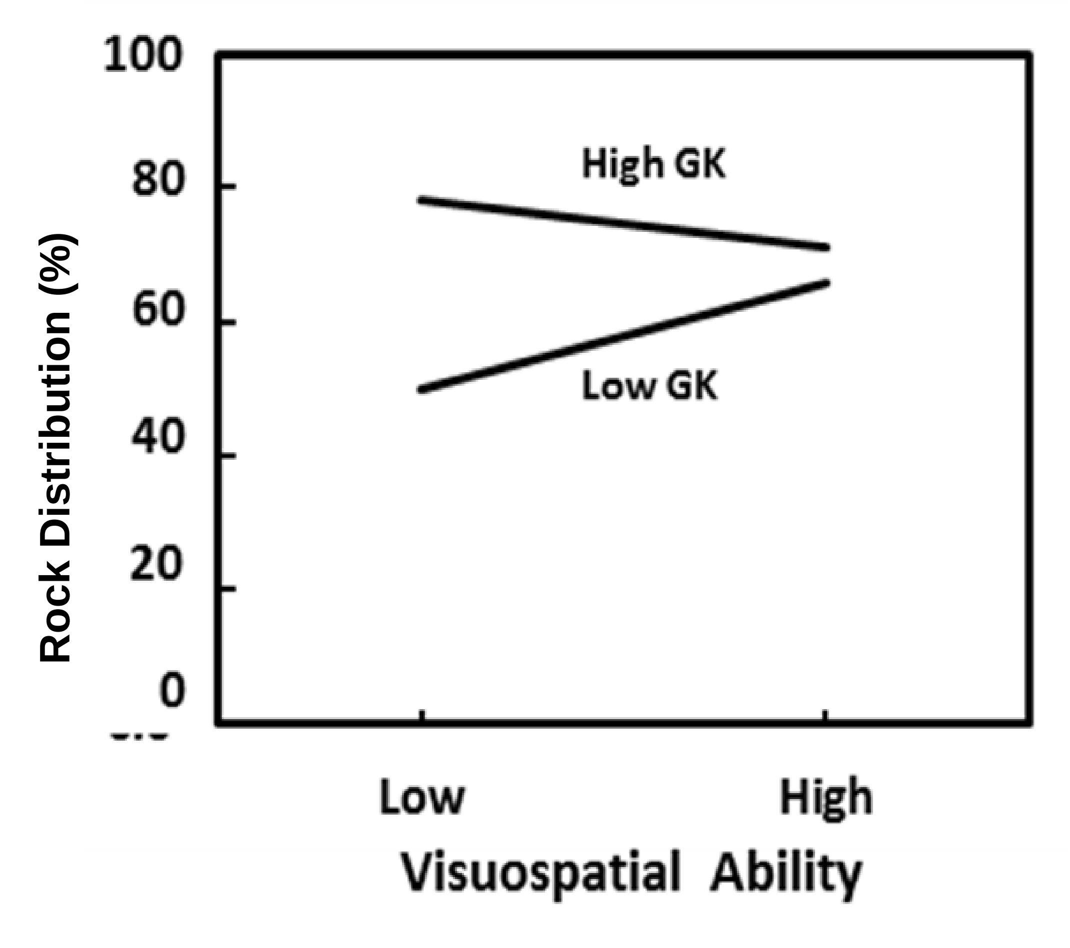
KNOWLEDGE

- Pencil/paper test
- Self-paced, individual
- Multiple choice, open-ended

Draw a representation of the intersection between a bedding plane and a fault on the stereonet below.



Study 1: Key Findings



FINDINGS

- Expertise correlates with knowledge
- At low knowledge (novice) spatial thinking has a positive effect on accuracy of rock distribution
- At high knowledge (expert) spatial thinking has little effect

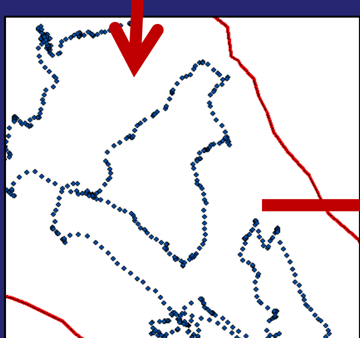
Do experts "see" the geology?

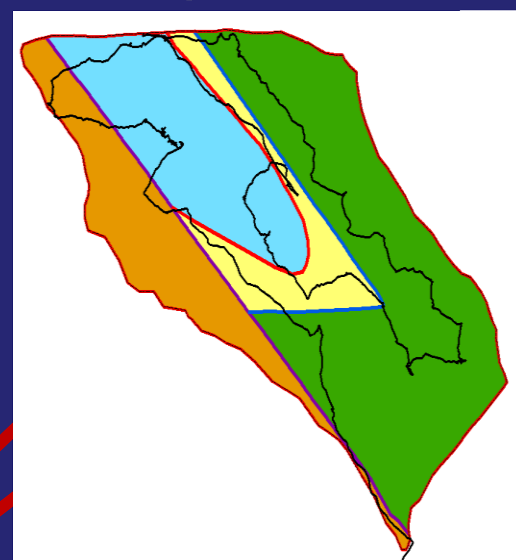
Hambrick et al., 2012

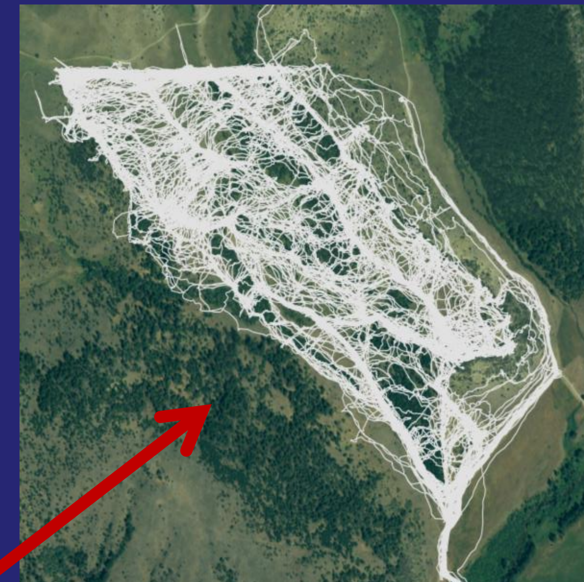
Study 2: Methods

GPS TRACK ANALYSIS

- Waypoints at 10s intervals
- Clean and import to ArcGIS
- Overlay tracks on maps
- Principle component analysis
- Spatial sequencing (ClustalG)







Study 2: Key Findings

PCA ANALYSIS

- Two components account for 84% of variability
  - Thoroughness and speed

	Rock distribution	Geologic structure	Thorough-ness
Geologic structure	.55**		
Thorough-ness	.46**	.27*	
Speed	NC	.36* / -.35	-.53**

Structure = Spearman's; All others = Pearson's
*p<.05
**p<.01

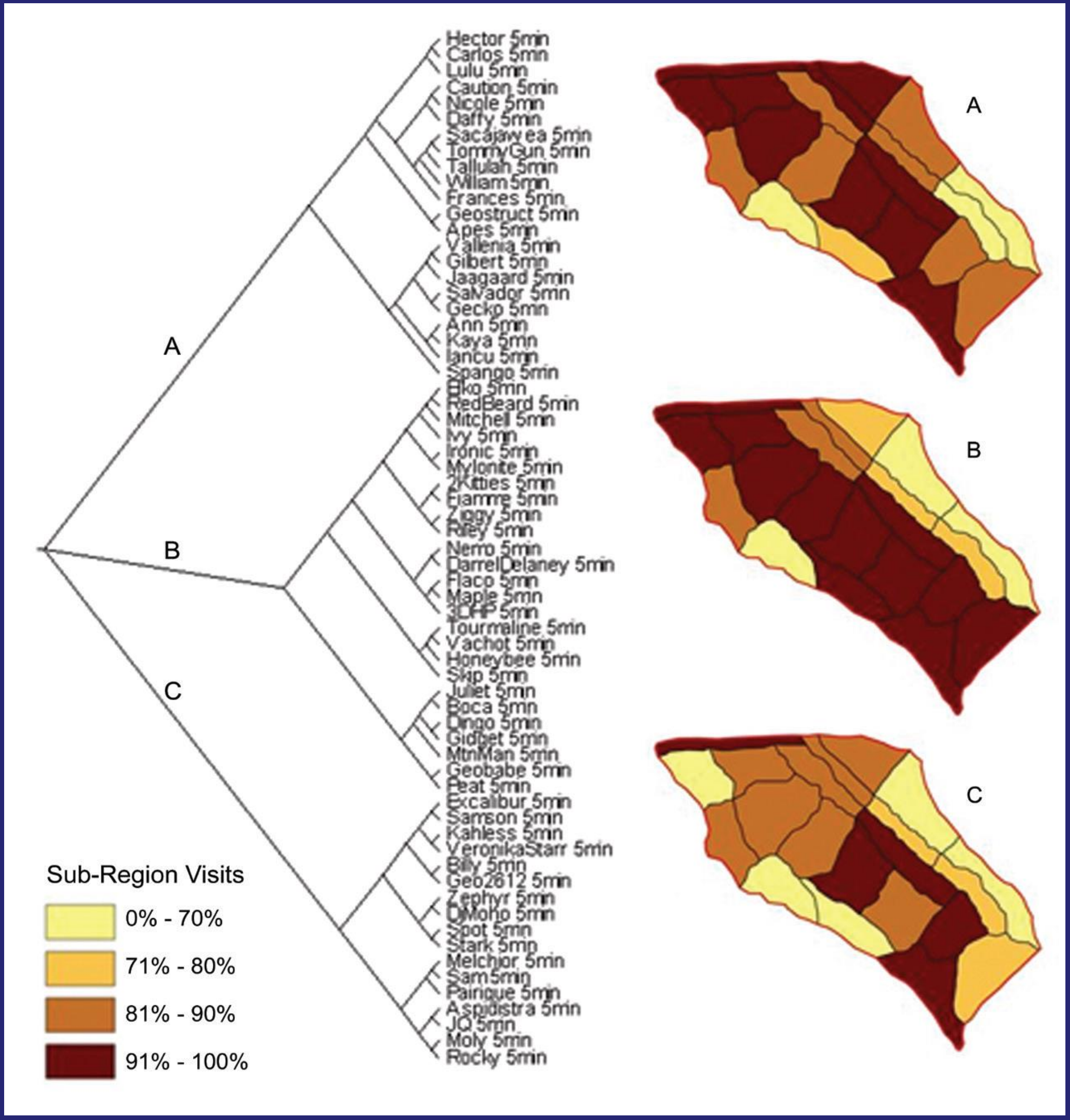
FINDINGS

- Visiting more of the field area produced a more accurate map
- Fast novices are less thorough and have poorer interpretations
- Fast experts had higher quality interpretations

Do experts "see" the geology?

Baker et al., 2012

Study 2: Key Findings

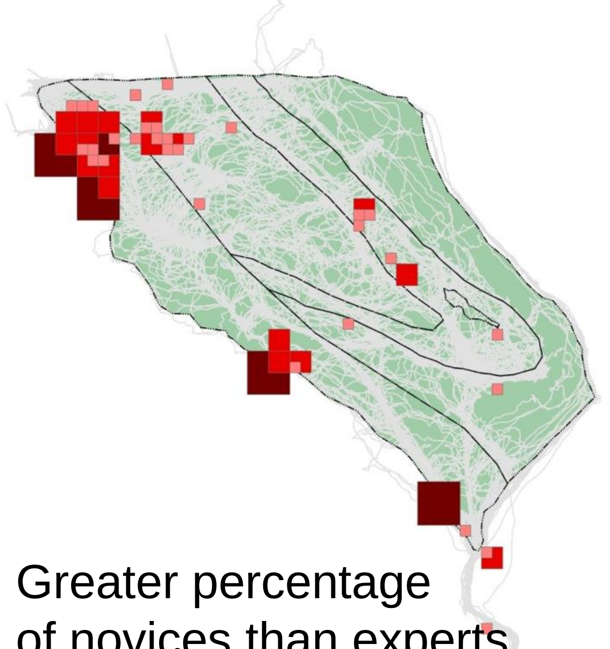


SPATIO-TEMPORAL SEQUENCING

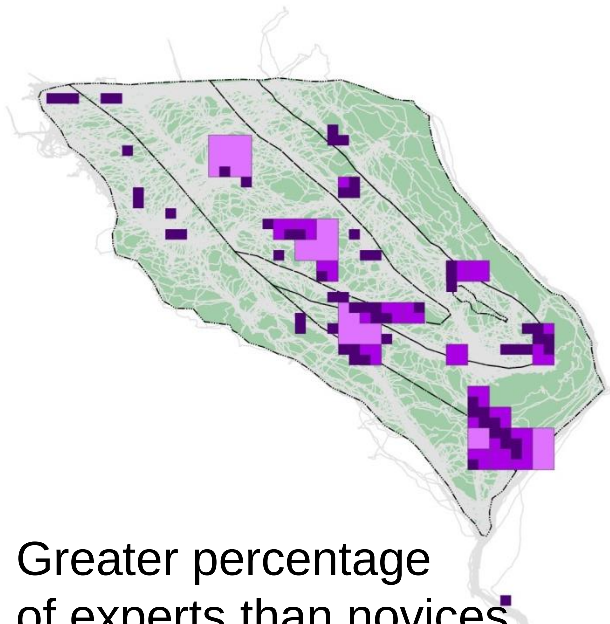
- Sequence A has:
  - 2 of top 10
  - 4 of bottom 10
  - 1 expert
- Sequence B has:
  - **7 of top 10**
  - **1 of bottom 10**
  - **5 experts**
- Sequence C has:
  - 1 of top 10
  - 5 of bottom 10
  - 2 experts

Baker et al., 2012

Study 2: Key Findings



Greater percentage of novices than experts



Greater percentage of experts than novices

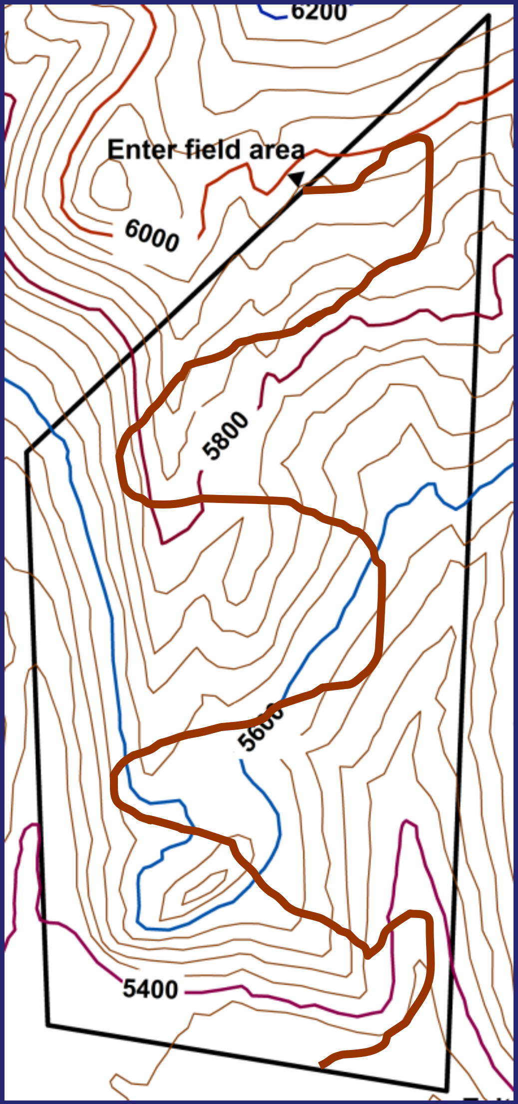
LANDSCAPE SENSITIVITY

- Identified areas that experienced mappers visited, compared all others
- Novices:
  - Concentrate time near entrance point
  - Spend more time around the perimeter of the area
  - Have more variable routes
- Experienced:
  - Concentrate time in geologically critical areas
  - Have more consistent routes

Do experts “see” the structure?

Baker & Petcovic, 2016

Study 2: Key Findings



USE OF CARTOGRAPHIC IMAGES

- Compare actual field routes to those drawn on a topo map in a survey administered at GSA
- Experts were statistically
  - More likely to use the aerial photo
  - More likely to articulate a specific plan of travel based on landscape features

Do experts "see" the structure?

Baker et al., 2016

Study 3: Methods

INTERVIEWS

- 30-45 min, post-mapping
- Audio, video recorded
- Transcribe interviews
- Develop coding scheme
- Code all interviews

INTERVIEWER: I was going to ask you about the zigzag again. Is that something that you were - why did you choose the zigzag to cover the area?

IRONIC (Int.): Well, first I didn't know exactly where I wanted to go, but I knew that I was probably going to be going downhill. And I didn't want to do a lot of - I wanted to conserve my energy as much as possible since I wasn't sure how long we were going to do this or how long it was going to take me to do it. So I just felt like if I zigzagged, I could cover a lot without having to backtrack too much, and I did end up backtracking a couple of times where I thought that I might have missed something. (Lines 262-269)

Had a zig-zag strategy heading mainly downhill from the launch point to field station so as to conserve energy and minimize amount of backtracking uphill, although did end up making some loops to get to missed areas

1. Mental model of the geology in the field site.
2. Development of the mental model.
3. Confidence in the map and/or model.
4. Factors affecting performance on the task.
5. **Navigation strategies**
6. Other

Study 3: Key Findings

COMMON NAVIGATION STRATEGIES:

- Get high for an overview
- Work downhill to save energy
- Avoid backtracking
- Find
  - Exposed rock
  - Contacts between units
- Avoid
  - Heavy cover
  - Steep slopes
  - Obvious geology
  - Cows!

PEAT (Nov.): Alright, my thinking going into this was, I needed to be able to see as much as I could see from one spot, and I knew that **this was the highest point from looking at the topo map** … I sat down and just looked at the area, looked at the terrain, I tried to reference myself to where all of the boundaries were and from this point. (58-72)

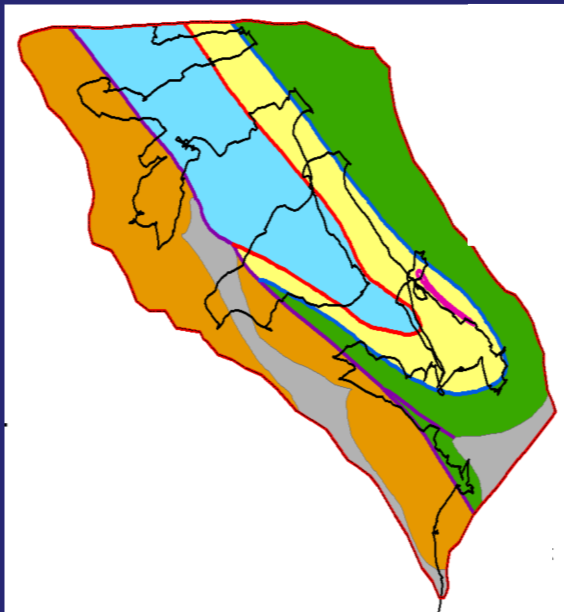
PARIQUE (Int.): I wanted to cover as much of the ground as I could **without having to, you know, do too much up and down hiking**. (225-228)

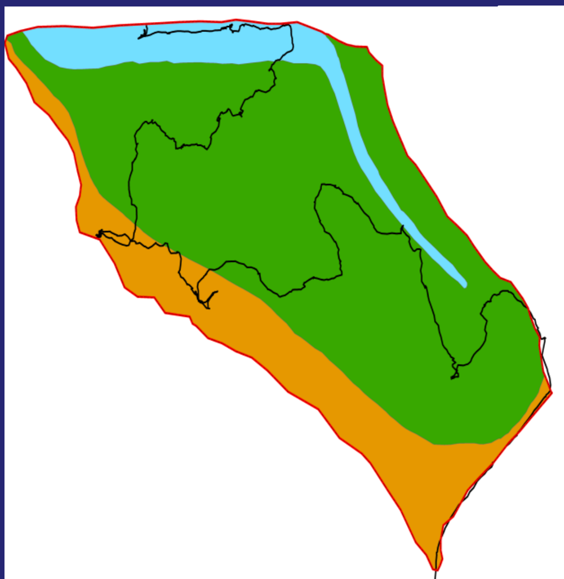
TANK (Exp.): So then the next thing I wanted to do was go **find some contacts and walk them**, you know, and that's just classic field geology…. (288-295)

MOLY (Nov.): **I did not go down along these kind of cliff faces** down here … I also looked at it and I decided that it was probably similar; that it was probably Unit 3 by the way that it was weathering. (178-182)

IRONIC (Int.): … I tried to **avoid the cows** like the plague, because I was a little frightened of them. (207)

Study 3: Key Findings





TWO TRACKS IN THE SAME CLUSTER:

INTERVIEWER: So, give me an overview of how you made this map? Where did you go? Where did you spend your time? What was your approach to doing this work?

2KITTIES (Exp.): Well, I started of course up here [*pointing at the launch area*], had a look at things, and really kind of the strategy was making a few transects **across this structure** [*gesturing back and forth perpendicular strike of unit*] not so much going down. I wanted to **look at the nose** actually straight away [*pointing to southern end of map area*] to see if I could get a better handle on what this unit was.

RILEY (Nov.): Okay. Well with previous field experience, they would suggest just look at the general area, get your bearings of course, find out where north is and everything. And then zigzag.

INTERVIEWER: And is there a particular reason you would use that approach?

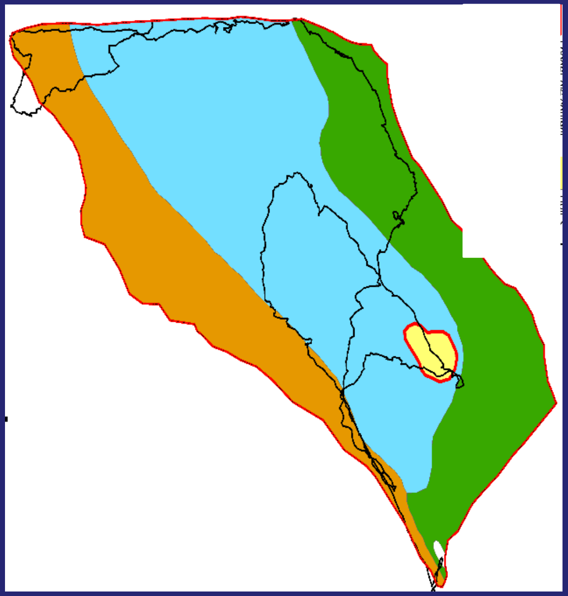
RILEY: Well, probably because **you are covering the general area**. And you can **visually see** that the rock as you progress is pretty much the same as what - where you had been at the last point.

Study 3: Key Findings

NOVICE STRATEGIES:

- Directly see as much of the area as possible
- Develop models during mapping (if at all)

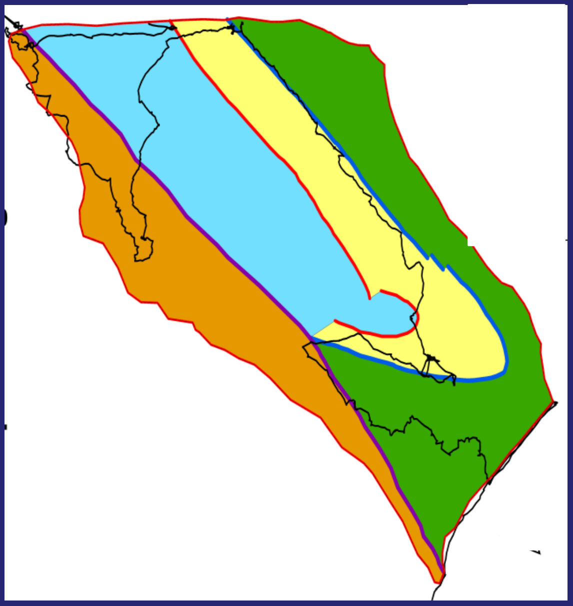
BOCA (Nov.): … So I was **just trying to cover the whole expanse**, but try to put a rhyme and a reason to it so that you don't leave any areas out. (Lines 214-234)



EXPERT STRATEGIES:

- Cross the geologic structure
- Follow the geologic structure
- Test models developed immediately (or early) in the day

GIDGET (Exp.): …you get to a point where it is really very similar and so the strike was just really **the limb of the fold**, on this side for sure. And so I just started drawing them [the contacts] in. And then I made sure **I walked them out** … (178-183)



What Does It All Mean?

Summary:

- Spatial thinking is important, BUT appears more important for novices
- Novices (lower geologic knowledge) rely on spatial thinking to construct their understanding of rock distribution and structures in the field, during the task using a strategy of covering as much of the area as possible
- Experts (higher knowledge) generate immediate mental models from maps and photos, and test hypotheses by visiting geologically critical areas

Implications for Field Instruction

TEACHING IMPLICATIONS

- Spatial thinking may be a “gateway” to the discipline, but knowledge is critical in mapping
- Need for explicit instruction in using maps and photos to develop working hypotheses
  - Push students to synthesize observations early and develop models of the underlying geology
- Need for explicit instruction in navigation choices that test working hypotheses
  - Rather than “cover” or “zig-zag,” teach how to recognize optimal locations for data collection and testing models

Questions?

Publications from This Project

Baker, K. M., Johnson, A. C., Callahan, C. N., & Petcovic, H. L. (2016). Use of cartographic images by expert and novice field geologists in planning fieldwork routes. *Cartography and Geographic Information Science*, *43*(2): 176-187. DOI: 10.1080/15230406.2015.1072735

Baker, K. M., and Petcovic, H. L. (2016). Sensitivity to landscape features: A spatial analysis of field geoscientists on the move. *Journal of Geoscience Education 64*(3), 242-253. DOI: 1089-9995/2016/64(3)/242/12

Baker, K. M., Petcovic, H. L., Wisniewska, M., & Libarkin, J. C. (2012). Spatial signatures of mapping expertise among field geologists. *Cartography and Geographic Information Science 39*(3), 119-132. DOI: 10.1559/15230406393119

Callahan, C. (2013). An embodied perspective on expertise in solving the problem of making a geologic map (Doctoral dissertation). Retrieved from http://scholarworks.wmich.edu/dissertations/186

Hambrick, D. Z., Libarkin, J. C., Petcovic, H. L., Baker, K. M., Elkins, J., Callahan, C. N., Turner, S. P., Rench, T. A., & LaDue, N. D. (2012). A test of the Circumvention-of-Limits hypothesis in scientific problem solving: The case of geological bedrock mapping. *Journal of Experimental Psychology: General, 141*(3), 397-403. DOI: 10.1037/a0025927

Petcovic, H. L., Stokes, A., & Caulkins, J. L. (2014). Geoscientists' perceptions of the value of undergraduate field education. *GSA Today, 24*(7), 4-10. DOI: 10.1130/GSATG196A.1